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Enhancing Chemical Process Control Education: A Self-Paced, AI-Assisted Approach to Strengthen ODE Modeling and Simulation Skills

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Abstract: This study explores the integration of AI tools, particularly ChatGPT, into engineering education to enhance learning in Ordinary Differential Equation (ODE) modeling in the course of Chemical Process Control. A self-paced, AI-assisted project was developed to refresh students' understanding of ODE modeling and improve their simulation skills. The project featured three progressively challenging ODE models: a car distance simulation, an enzymatic reaction, and a fed-batch bioreactor, with students using Python and ChatGPT for guidance. To evaluate feasibility, the project was tested in Summer and Winter 2024 by nine high school volunteers with limited prior exposure to ODE modeling. All participants successfully simulated the models using Google Colab, achieving high quiz accuracy rates (100% on ODE model understanding, 66.7% on numerical methods, and 77.78% on applying bioreactor concepts). Surveys revealed increased confidence in ODE modeling, Python coding, and using AI tools, with students citing ChatGPT's effectiveness in providing timely support. Challenges included difficulties in modifying AI-generated code and understanding complex terminology terms in ODE models. Student feedback highlighted areas for improvement, such as clearer guidance and expanded ODE examples. This pilot demonstrates the potential of AI-driven learning to transform engineering education and will inform further refinement for its application in college-level Chemical Process Control courses.

Introduction

Artificial Intelligence (AI), notably the use of ChatGPT, has become increasingly prevalent in the academic world. ChatGPT's ability to quickly dispense answers from a self-inputted prompt allows students to utilize this tool to aid comprehension of difficult topics. This novel technology is not the first type of AI to aid learning for students and researchers. Agent-based modeling (ABM) is a prior approach that has been successfully applied to mathematics and biology education [1]. ABM can simulate epidemic outbreaks, urban planning, and evolutionary processes, which all involve intricate interactions that can be difficult to predict utilizing traditional models. ABM is an example of how technology and modeling can provide improved pedagogical methods. However, as the number of students pursuing STEM education continues to rise, there is an increasing demand for more effective and personalized teaching approaches that enhance critical-thinking skills [2]. Specifically, in introductory Calculus courses, textbooks have been progressively updated to integrate real-world applications of modeling, particularly those involving computer systems and data science [2]. An appropriate use of technology can enable students to better visualize the problem sets at hand. The rise of ChatGPT and AI in educational settings prompts further efforts to help students grasp difficult concepts. For instance, educators have used ChatGPT to

create step-by-step explanations of complex problems, allowing students to explore multiple solution pathways [3]. Additionally, ChatGPT has been integrated into programming courses to debug code, explain algorithms, and offer personalized learning recommendations based on student performance [4]. These examples highlight ChatGPT's potential to complement traditional teaching methods for deeper engagement with STEM subjects.

The course Chemical Process Control involves ordinary differential equation simulation, and while students typically take process modeling before studying process control, they may forget essential ODE concepts over time. Emerging research indicates insufficient math preparation is a large factor in the high attrition rates of undergraduate engineering majors [5]. Specifically, the phenomenon referred to as the Calculus "bottle neck" leads to the early attrition of many prospective engineering majors [6]. It is therefore challenging to instill confidence and excitement in students when teaching ODE modeling. It is indicated by in the literature that introducing students, including high-school students, with real-world application of ODE modeling can inspire students for a STEM career path [7–10]. While these cases relied on MATLAB or R, guided by the instructor's detailed instructions, emerging AI technologies offer a promising alternative to inspire students' self-paced learning and spark their interest in pursuing STEM career paths. To address this, this project aims to implement ChatGPT and AI as supplementary tools for studying ODE models in the course Chemical Process Control.

While this project is ultimately designed for senior students taking Chemical Process Control in Spring 2025, nine high school students of differing mathematical and coding backgrounds voluntarily participated in a pilot study in Summer 2024. The nine high school students were recruited through connections with local high schools and friends, ensuring a diverse mix of grade levels (one 9-grader, two 10-graders, four 11-graders, and two 12-graders), genders (four female students and five male students), ODE mathematics experience (four with no-experience, three with limited experience, one with moderate experience, and one with extensive experience), and programming (one with no-experience, four with limited experience, and four with moderate experience). The voluntary selection aimed to include students with diverse backgrounds to evaluate the accessibility of AI-assisted ODE modeling across skill levels, based on students' self-perceptions in the anonymous survey. The students had taken a variety of STEM-related subjects, including Basic Algebra, Calculus, Biology, Physics, and Programming. Some students had broader exposure to multiple programming languages (e.g., Python, Java), while others had primarily studied mathematical concepts without direct coding experience. These variations in prior knowledge contributed to the diversity in their mathematical and coding backgrounds.

The hypothesis studied in this study was that if high school students with limited exposure to ODE modeling and simulations could complete the project, senior college students would also succeed. The aim was to use student feedback for improvements. In this project, Python, which is the most popular coding language in AI [11,12], was introduced to students, along with the free and powerful Python-coding platform, i.e., Google Colab. After completing the self-paced problem set, with the support of ChatGPT, participants gave anonymous feedback on their experience with using ChatGPT and Google Colab and their interest in ODE modeling and STEM-related topics. The results and student feedback were thoroughly analyzed, and the implementation of this pilot study, initially conducted with high school students, was also discussed in the context of its potential application to college students.

Materials & Methods

Introduction of the Three ODE Models

Students were tasked with three ODE models closely related to their daily life, each increasing with progressive difficulty. The first ODE model (Figure 1) asked students to quantify and compare the distances of two cars based on given accelerations and times. The model asked students to plot the acceleration and time of two cars and compare the final distances. This ODE model was a beginner task, which was able to be validated by a simple physics distance equation, $d = \frac{1}{2}at^2$, aimed to provide an insight into how ODE models were structured and how questions could be asked in ChatGPT. The initial conditions, along with the parameter value, were offered to students before the simulation.

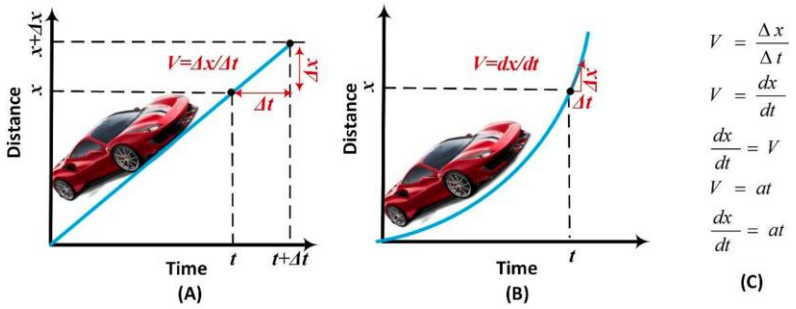
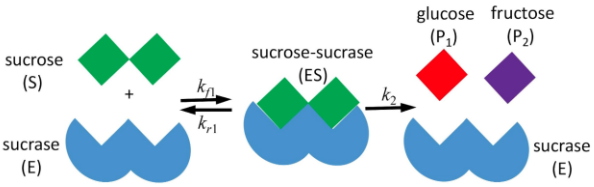


Figure 1, the ODE model for the distance simulation of cars at different acceleration rate

The second ODE model focused on a classic enzyme kinetics framework (Figure 2), describing how the enzyme sucrase catalyzes the breakdown of sucrose into glucose and fructose, which contributes to the sweet taste perceived in the mouth. Students were assigned to simulate this ODE Model in Python. They were to create a 10-second simulation which in turn would produce the profiles of proteins for the given initial values and parameters.



$$\frac{dC_E}{dt} = (k_{r1} + k_2)C_{ES} - k_{f1}C_E C_S$$

$$\frac{dC_S}{dt} = k_{r1}C_{ES} - k_{f1}C_E C_S$$

$$\frac{dC_{ES}}{dt} = k_{f1}C_E C_S - (k_{r1} + k_2)C_{ES}$$

$$\frac{dC_P}{dt} = k_2 C_{ES}$$

Figure 2, the ODE model of the enzymatic processes in which sucrase converts sucrose to glucose.

For the third and final ODE model, students were given the mathematical model for the bioreactor with the parameters, and the initial values of the variables at time zero (Figure 3). This bioreactor model describes how therapeutic products, such as vaccines, are produced from the manufactured cells. Students were to develop a Python model that would evaluate how the flow rate may change the performance of the bioreactor in a 30-hour duration. In particular, students studied how the flow rate impacted the cell biomass, the substrate consumption, the product concentration, and the volume change over time.

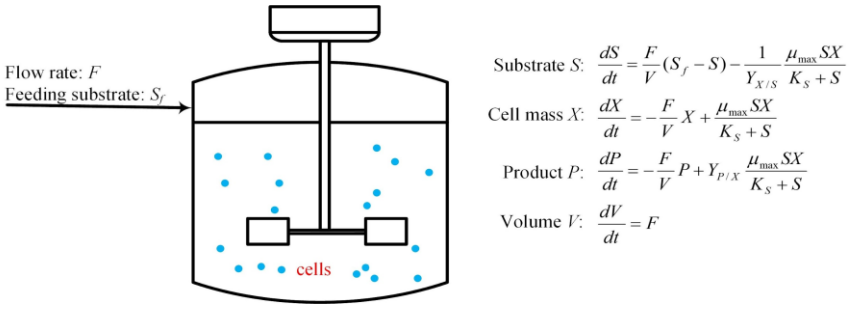


Figure 3, the ODE model of a bioreactor model in which therapeutic product (i.e., *P*) is produced by the cell (i.e., *X*) from the substrate (i.e., *S*) fed at the flowrate of *F* in the volume of *V*.

The Application of ChatGPT in Guiding Students' Learning

ChatGPT was used to guide student learning throughout this ODE simulation project. ChatGPT is one of the most popular artificial intelligence (AI) chatbot developed to generate human-like text [13,14]. This AI machine can be used to understand and respond to questions, and developmental subjects, and will compose written content, answering the user's request. Students used ChatGPT to understand specific terms as well as numerical solutions when solving ODE models. When students learned to use Python, they understood this coding language by utilizing ChatGPT and asking specific questions to better comprehend the codes and programs. Examples of what students asked ChatGPT about included questions like "Define this term in relation to an ODE Model," "What are the key variables and parameters of this equation," and "Provide example Python programs similar to what this ODE Model is asking." Finally, students applied their models to open-ended, real-world scenarios chosen by themselves.

Implementation of the Project

In this self-paced, ChatGPT-based online learning project, the instructor provided students with a handout containing three ODE models, ranked by difficulty: the car distance model, the classical enzymatic model, and the fed-batch bioreactor model. Example questions were included to guide students in using ChatGPT to understand each term in the ODE models, numerical solutions used to solve ODE models, Python coding in Google Colab to simulate ODE models. All these materials were shared in a Google Classroom where students asked questions or shared their thoughts. Students learned the physical meaning of ODE models from the handout and the conversation of ChatGPT. They were encouraged to learn Python coding and ODE simulation in Python with the support of ChatGPT. Once they checked their results, mainly via the simulation files, they then applied their models to open-ended, real-world scenarios chosen by them. All students were connected through Google Classroom to inspire collaborative learning. Students conducted a completely self-paced project in Python. At the end of the project, they submitted their project portfolio as well as a Word document showing their overall understanding of ODE models. In their Word document, students provided a short description of the three ODE models and their results. To measure learning progression, students completed a short anonymous pre-project and post-project quiz administered through Google Forms. These assessments provided insight into their development in both ODE concepts and Python coding skills.

Evaluation of students' learning

The instructor graded the students with a focus on their written understanding of the three ODE models, their recorded simulation results, and the accuracy and functionality of their Python code implementations. Additionally, an anonymous survey assessed the group's knowledge of ODE modeling and Python programming as a whole. The survey was split into four sections:

- Demographic Information: To understand the backgrounds of the student group, this section focused on questions related to their grade level, gender, and previous experience with Python programming and ODE modeling. Students also shared their level of access to technology, such as whether they had a personal computer and internet. This information was critical in analyzing how various factors, like prior exposure to coding or technology access, influenced their performance and engagement with the project.
- Student Improvement: The second section evaluated how much students improved in their understanding of ODE models and their ability to implement them using Python. It included questions that measured confidence in solving ODEs, simulating them in Python, and applying these models to real-world scenarios such as bioreactors. Students rated their confidence levels before and after the project. Additionally, this section included four multiple-choice quiz problems to quantify their ODE model understanding, numerical methods (such as Euler's method), Python coding (such as Scipy for ODE simulations), and the bioreactor model.
- Learning Experience: The role of AI tools, such as ChatGPT, in enhancing the students' learning experience was explored in this section. Students reflected on how helpful AI was for understanding advanced concepts. Example questions asked how often AI was used and what types of questions students posed to the AI. Furthermore, this part investigated whether AI-assisted learning made students feel more confident about STEM concepts or expanded their curiosity about using AI in future projects.
- Student's Opinion: The final section allowed students to reflect on their overall experience with the project. Open-ended questions invited students to share what they found the most enjoyable and most challenging part about the project. They were also asked to provide suggestions for improving the project in future iterations. This section included questions to gauge whether students would recommend the project to their peers and whether it motivated them to pursue a career in STEM. The feedback collected in this section was essential for understanding the project's impact on student satisfaction.

Results and Discussion

Evaluation of Students' Improvement in Modeling and Coding Skills

The AI-assisted ODE modeling project was designed to assess and improve students' ability to develop and simulate ODE models using Python. Nine students entered the project with varying levels of experience: while four students had moderate programming knowledge from coursework or personal projects, one student reported no prior programming experience. Similarly, seven students had minimal or no exposure to ODE models before the project began.

Some key findings from the evaluation are listed below:

- Completion Time: All nine students (one 9th-grader, two 10th-graders, four 11th-graders, and two 12th-graders) completed the project within an average of 5.0 ± 2.1 hours, demonstrating the feasibility of the self-paced format.
- Project Completion: all nine students were able to develop and simulate all three ODE models (car distance, enzymatic reaction, and fed-batch bioreactor) successfully.

- Coding Accuracy: Most students displayed strong coding proficiency, though minor errors were observed when attempting to modify AI-generated code.

Despite differences, all participants successfully completed the tasks. The self-paced project allowed students to balance learning with exploration. Post-project survey data revealed significant growth in confidence (Table 1): understanding ODE models improved from an average score of 1.8 to 2.9 (on a 4-point Likert scale with 1 lowest and 4 highest), Python coding confidence rose from 2.3 to 2.7, and using AI tools to grasp unfamiliar concepts (e.g., ODE modeling, enzyme dynamics, bioreactor processes) increased from 2.6 to 3.2. These gains highlight the project's success in making STEM learning more accessible and engaging through AI-assisted, self-paced education. The ability to construct and simulate ODE models reflects both conceptual understanding and practical skills essential for advanced STEM work. The self-paced format, supported by AI tools like ChatGPT, reduced the intimidation of technical subjects by providing immediate feedback and explanations, acting as "virtual tutors" that bridged knowledge gaps. This underscores the value of adaptive technologies in STEM education.

Table 1. The distribution of self-perceptions in the survey based on a 4-point Likert scale from 1 (least confident) to 4 (most confident):

Skill Area	Pre-Project Average	Post-Project Average
Understanding ODE models	1.8	2.9
Solving ODEs in Python	2.3	2.7
Using AI tools for learning	2.6	3.2

In the multiple-choice quiz to evaluate students' understanding of ODE modeling and coding, the results (Table 2) showed all nine students returned correct responses in "ODE model understanding," indicating strong grasp of ODE fundamentals. Eight and seven students provided correct answers to Sections "bioreactor parameters" and "numerical methods". This reflected students' ability to understand methods like Euler's method and interpret bioreactor variables. However, only six students got the correct answer for the quiz question on "Python coding", suggesting students may need more practice with Python syntax and functions. Overall, the quiz confirmed students' conceptual understanding and retention of practical knowledge, reinforcing self-reported confidence gains and identifying areas for further improvement.

Table 2. Students' scores on the quiz based on the 4 topics of questions to evaluate the learning from the project

Question Category	Number of Students
ODE model understanding	9
Numerical methods	7
Python coding	6
Bioreactor parameter	8

Survey Results on Evaluating Students' Learning Experience

The post-project survey aimed to capture students' learning experiences and perceptions of the AI-assisted format. Responses were collected on a 4-point Likert scale, where 1 indicated "strongly disagree" and 4 indicated "strongly agree."

Key questions focused on the following aspects:

- Perceived Helpfulness of ChatGPT: Most students rated ChatGPT as helpful for understanding Python syntax, ODE modeling, and clarifying doubts, with an average score of 3.2.
- Interest in STEM: The survey recorded a slight increase in STEM interest, from a pre-project average of 2.7 to 3.1 after project completion.
- Independent Learning and Problem-Solving: Students appreciated the autonomy provided by the project, reporting satisfaction with their ability to overcome coding challenges and complete simulations independently.

The data underscores the potential of AI-based educational tools to foster both conceptual understanding and confidence in students. The high perceived helpfulness of ChatGPT demonstrates that the tool effectively served as a virtual assistant, helping students troubleshoot errors and understand key ODE concepts. This finding is especially significant as it shows how AI can bridge the gap between traditional classroom instruction and independent learning, without a great loss in effectiveness. Furthermore, the increase in STEM interest, though modest, reflects the impact of real-world applications in making abstract mathematical modeling more engaging. Also, in the context of the sample, there was a high, preexisting interest in STEM to begin with of 2.7 out of 4. As such, the true extent of the impact on STEM interest is not best seen in the results of this sample, but it still must be noted that there still was an increase despite existing interest. Consequently, it can be found that, by contextualizing ODE models within familiar scenarios, such as car dynamics, the project helped students see coding as a practical tool rather than a theoretical exercise.

Survey Results on the Open-Ended Questions for Students' Comments on the AI-Based Self-Paced ODE Modeling Project

The open-ended question section at the end of the survey was intended to evaluate the students' opinions on the AI-based independent study experience and to identify areas of future improvement. The results for the three open-ended survey questions, i.e., "what was the most challenging aspect of this project for you?", "what did you enjoy most about the project?" and "what suggestions do you have for improving the AI-assisted STEM outreach program", are listed below.

Challenges With Conceptual Understanding and Code Implementation: Survey results indicate that students had difficulty in two main areas throughout the AI-guided individual study assignment: gaining a conceptual understanding of ODE models and sorting through AI-generated Python code to decipher its purpose and function (Table 3). Five of nine students surveyed reported that they found ODE models challenging to understand and four students experienced difficulties writing and editing code with AI guidance, showing that these issues were very prevalent among the individuals surveyed. These results highlight challenges associated with the complex nature of AI-generated answers explaining the ODE modeling process and the downsides of using AI as an assistive coding tool. Despite some drawbacks associated with AI-guided exploration, it is nonetheless a useful tool that shows promise in guiding students through the learning process.

Table 3. Challenges faced when completing the project and their prevalence

Challenges	Numbers of Students
Understanding ODE Models	5
Writing/Editing Code with AI	4

Enjoyment After Understanding ODE Models and Experiencing Coding Success: Students reported that there were two main things they enjoyed when completing the ODE modeling project (Table 4): being able to explain how the ODE models worked and to write functioning code that correctly represented the ODE models provided by the assignment. Five of students reported that they enjoyed successfully learning about the underlying mechanisms behind the ODE models, and the other four stated that successful coding was the main source of their enjoyment while doing the project. These results demonstrate that the most challenging portions of the AI-guided ODE modeling project for the students were also the most enjoyable parts of the process. Evidently, learning about ODE models with the help of AI guidance is an extremely rewarding experience for the students involved and can teach them valuable problem-solving skills.

Table 4. Sources of enjoyment when completing the project and their prevalence

Reason	Numbers of Students
Success With Understanding ODE Models	5
Success With Coding	4

Suggestions for Guided Instructions and ODE Model Complexity: Survey responses (Table 5) show that six students left a suggestion for improving the course, while the other three students did not. Responses to the last survey question indicate that there are three main areas for future improvement: the provision of more detailed guidance and instruction to help students through the ODE modeling project, a proposed reduction in the complexity of the problems given, and an increase in the number of problems assigned to the students. Three of students who responded to this question requested that additional guidelines and instructions be added to the project description, one student felt that the ODE models were too complex and unfamiliar, and one student asked for a higher volume of example problems. These results underscore potential flaws in the current design of the AI-based self-study experience on ODE modeling and are a useful tool to inform future revisions to the project. Using AI as a virtual tutoring tool is immensely useful, but students may need more detailed guidance on how to proceed since many reported that they felt confused due to the open-ended nature of the independent study assignment. In addition, more specific and targeted practice in the form of more ODE model examples may be pertinent, since some students found the shift from the car model to the bioreactor model to be abrupt and confusing and others asked for extra practice to reinforce their understanding of basic ODE modeling concepts.

Table 5. Student suggestions for project improvement and their prevalence

Suggestion	Numbers of Students
Add More Detailed Instructions	3
Reduce Complexity of ODE Models	1
Add More ODE Model Examples	1

Discussion of Limitations and Future Plans

This study was conducted with a small sample of nine high school students, which may limit the generalizability of the findings. However, to strengthen the validity of our results, we will implement this project with 60 senior college students in an upcoming study. This larger sample size will provide more comprehensive data on the effectiveness of AI-assisted learning in ODE modeling and allow for a more rigorous evaluation of its impact on student learning outcomes. Compared to high school students, college participants will engage with more advanced quiz problems designed to evaluate their deeper understanding of ODE simulations and their ability to apply mathematical modeling in engineering contexts. Additionally, while high school students focused on fundamental ODE applications, college students will tackle more complex, real-world design challenges. For example, they will use ODE models to optimize bioreactor operation and design, considering variables such as substrate consumption, product yield, and system dynamics. This comparative study will measure differences in conceptual mastery, problem-solving skills, and engagement between high school and college students, providing valuable insights into the effectiveness of AI-assisted learning in higher education.

While five of the night high school students surveyed reported finding ODE models challenging to understand, senior chemical engineering students taking process control courses may not face the same difficulty. These students typically have a stronger foundation in ODE modeling due to their prior coursework. However, interacting with ChatGPT can still serve as a valuable tool to refresh their understanding and reinforce key concepts. For senior students in the chemical process control course, the level of difficulty in ODE-based projects will be adjusted to align with their advanced knowledge and experience. For instance, while high-school students worked on basic simulations, senior students will be tasked with dynamic system modeling involving multiple interacting variables, such as simultaneous heat and mass transfer processes. These projects will include optimization problems and real-world applications, to offer a more rigorous learning experience. Additionally, the pedagogy will be upgraded to include collaborative projects where students use ChatGPT to solve complex problems in teams, fostering peer learning and collaboration.

While the use of AI tools like ChatGPT is novel and transformative, some students might express concerns about the energy requirements of AI or may prefer not to interact with AI tools directly. To accommodate these preferences, alternate learning resources will be provided. These resources may include detailed step-by-step guides, pre-recorded video tutorials, and self-paced coding exercises. This ensures that all students, regardless of their comfort level with AI, can engage with the material and achieve the learning objectives. By addressing the diverse needs and preferences of students and continuously evolving the teaching methodology, this approach aims to create an inclusive and effective learning environment that leverages the transformative potential of AI in engineering education.

Conclusion

The purpose of this study was to collect feedback from an AI-guided self-study pilot project on ODE modeling done by high school students for further application in a Chemical Process Control course taken by college senior students. The project instructions included diagrams and differential equations for three different types of ODE models: a car driving distance model, an enzyme reaction model, and a bioreactor model. Students were then asked to answer questions that required a conceptual understanding of the models and to show their work and results after working through each of the examples with AI guidance. Lastly, an anonymous survey was administered after the project to assess the proficiency levels of the students and the efficacy of the AI-assisted independent study program. The results of this study indicate that students developed a greater proficiency with Python programming and ODE modeling through AI-based learning. Specifically, they expressed an increase in confidence levels across all skill areas—understanding ODE models, using Python to simulate ODEs, and utilizing AI tools for learning. In addition to the self-reported confidence levels, the students demonstrated a strong comprehension of fundamental concepts of ODEs and numerical methods on a quiz designed by the instructor, corroborating the previous confidence. Notably, the study also produced an increase in students' interest for STEM as well as an active engagement with the AI tutor: frequently using AI to debug and explain parameters to the problems. However, the study's small sample size of 9 high school students and the voluntary basis for student selection are potential limitations that may have restricted the representativeness of the data collected, since results were generalized to all college students. Response bias may have also played a role in skewing the results of subjective parts of the survey, such as the students' self-evaluations of their understanding of and experience with the project. To further improve on this current baseline project, future iterations would incorporate a more structured guidance. Such scaffolding could include step-by-step tutorials and prompt engineering for advanced models along with a wider range of ODE examples to build coding fluency strengthen problem-solving skills. Expanding the project in this manner in addition to the sample itself would provide insights into the overall scalability and adaptability of AI-tutoring across education levels, such as a demonstration in a senior-level Chemical Process Control course.

References

1. Bodine, E. N., Panoff, R. M., Voit, E. O. & Weisstein, A. E. Agent-Based Modeling and Simulation in Mathematics and Biology Education. *Bull Math Biol* **82**, (2020).
2. Jungck, J. R., Robeva, R. & Gross, L. J. Mathematical Biology Education: Changes, Communities, Connections, and Challenges. *Bull Math Biol* **82**, (2020).
3. Kasneci, E. *et al.* ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences* vol. 103 Preprint at https://doi.org/10.1016/j.lindif.2023.102274 (2023).
4. Finnie-Ansley, J., Denny, P., Becker, B. A., Luxton-Reilly, A. & Prather, J. The robots are coming: Exploring the implications of OpenAI codex on introductory programming. in *ACM International Conference Proceeding Series* (2022). doi:10.1145/3511861.3511863.
5. Correll, S. J., Seymour, E. & Hewitt, N. M. Talking about Leaving: Why Undergraduates Leave the Sciences. *Contemp Sociol* **26**, (1997).
6. Hsu, E. & Bressoud, D. Insights and Recommendations from the MAA National Study of College Calculus. *Insights and Recommendations from the MAA National Study of College Calculus* (2015).

7. Guo, P., Yuan, K. & Huang, Z. Develop Web-based Modules to Educate High-School Students in Studying Microbial Fuel Cell Dynamics. in (2024). doi:10.18260/1-2--29253.
8. Huang, Z. Design a Modeling STEM Outreach Project to Promote High-School Students' Interest in Math-Related Research. in (2024). doi:10.18260/1-2--36293.
9. Geng, J. COMPARISON OF R AND MATLAB SIMULINK in Educating High School Students with ODE Modeling Skills. *Chem Eng Educ* **53**, (2020).
10. Li, X. & Huang, Z. (Jacky). An inverted classroom approach to educate MATLAB in chemical process control. *Education for Chemical Engineers* **19**, (2017).
11. Paszke, A. *et al.* PyTorch: An imperative style, high-performance deep learning library. in *Advances in Neural Information Processing Systems* vol. 32 (2019).
12. Millman, K. J. & Aivazis, M. Python for scientists and engineers. *Computing in Science and Engineering* vol. 13 Preprint at https://doi.org/10.1109/MCSE.2011.36 (2011).
13. Goktas, P., Karakaya, G., Kalyoncu, A. F. & Damadoglu, E. Artificial Intelligence Chatbots in Allergy and Immunology Practice: Where Have We Been and Where Are We Going? *Journal of Allergy and Clinical Immunology: In Practice* **11**, (2023).
14. Ray, P. P. ChatGPT: A comprehensive review on background, applications, key challenges, bias, ethics, limitations and future scope. *Internet of Things and Cyber-Physical Systems* vol. 3 Preprint at https://doi.org/10.1016/j.iotcps.2023.04.003 (2023).